Forest Research Information Paper 165

Wood Supply in Ontario:
The Road to Better Prediction

Ontario

Ontario Forest Research Institute
OFRI · IRFO

Forest Research Information Paper No. 165

Wood Supply in Ontario:
The Road to Better Prediction

Jean-Marie Sobze, Michael T. Ter-Mikaelian, and
Stephen J. Colombo

Ontario Forest Research Institute
Ontario Ministry of Natural Resources
1235 Queen Street East
Sault Ste. Marie, Ontario
Canada P6A 2E5

2006

APPLIED RESEARCH AND DEVELOPMENT • ONTARIO MINISTRY OF NATURAL RESOURCES

Library and Archives Canada Cataloguing in Publication Data

Sobze, Jean-Marie
Wood supply in Ontario : the road to better prediction

(Forest research information paper, ISSN 0319-9118 ; no. 165)
Includes bibliographical references.
Available also on the Internet.
ISBN 1-4249-2590-8

1. Forest productivity—Ontario—Forecasting.
2. Forests and forestry—Ontario—Forecasting.
3. Timber—Ontario—Forecasting.
I. Ter-Mikaelian, Michael.
II. Colombo, S.J. (Stephen John).
III. Ontario Forest Research Institute.
IV. Title.
V. Series.

SD387 F58 S62 2006 333.75'1109713 C2006-964030-0

© 2006, Queen's Printer for Ontario
Printed in Ontario, Canada

Single copies of this publication are available from:

Ontario Forest Research Institute
Ministry of Natural Resources
1235 Queen Street East
Sault Ste. Marie, ON
Canada P6A 2E5

Cette publication hautement spécialisée *Wood Supply in Ontario: The Road to Better Protection* n'est disponible qu'en anglais en vertu du Règlement 411/97, qui en exempte l'application de la Loi sur les services en français. Pour obtenir de l'aide en français, veuillez communiquer avec le ministère de Richesses naturelles au (705) 946-2981

This paper contains recycled materials.

Executive Summary

A secure and predictable wood supply is critical to the health of Ontario's forest industry. Wood supply is predicted using a number of data sources and models. Forecasting wood supply requires that long-term silvicultural activities be defined and forest growth, succession, natural disturbance, and harvest rates be predicted for periods of 100 or more years. This report identifies and prioritizes issues affecting wood supply prediction and recommends actions to improve the process of estimating wood supply.

To assemble the prioritized list of issues, we sought expert opinion from forestry specialists in Ontario through an electronic survey and a workshop. Overall, 42% of issues identified as contributing to uncertainty in wood supply estimation were related to forest resources inventory and growth and yield. The higher importance placed on these two themes compared to forest succession, natural disturbances, climate change, and the effect of guides does not mean that elements of these other issues are unimportant.

The top 5 areas considered most in need of improvement are (in order of importance):

1. Improved linkages between forest resources inventory and growth and yield data (for example, development of a method to calibrate/validate one with another, and improved methods of assigning growth and yield curves to stands in forest resources inventory).
2. More realistic information to predict and validate successional changes at various stages of stand development.
3. Additional growth and yield curves for planted and naturally regenerated stands.
4. Forest resources inventory updated more frequently.
5. Better data on factors affecting site productivity (for example, soil moisture and nutrient regimes) and inclusion of these factors in growth and yield models.

To develop a plan for addressing issues of uncertainty in wood supply prediction, we propose that the following steps be taken. First, clearly describe each issue. Second, develop a list of ongoing or recent projects relevant to Ontario's needs for addressing wood supply prediction. Third, evaluate the assembled list to assess the speed with which the needs can be addressed, the cost to address them, and the degree to which wood supply estimates would be improved. This will provide a prioritized list from which an action plan could be prepared.

Resumé

Des moyens pour mieux prédire les volumes de bois exploitables en Ontario

Pour assurer la stabilité du secteur forestier de l'Ontario, il est d'une importance cruciale d'avoir des volumes de bois prévisibles et garantis. Les prévisions à cet égard reposent sur un certain nombre de modèles et de sources de données, qui aident à définir les activités sylvicoles sur une assez longue période, puis à prévoir les taux de croissance des peuplements forestiers, les stages de succession, les perturbations naturelles et les taux de récolte sur une période de 100 ans ou même plus longue. Dans le présent rapport, nous avons exposé et classé sur une échelle de priorités diverses questions liées à la prévision des volumes de bois exploitables. Nous avons ensuite recommandé des moyens d'améliorer la méthode utilisée pour faire les prévisions.

Pour établir la liste des priorités, nous avons demandé à des spécialistes en foresterie de l'Ontario de nous présenter leurs opinions au moyen d'une enquête électronique et par leur présence à un atelier. Dans l'ensemble, 42 % des questions que les spécialistes ont dit se rapporter à l'incertitude des estimations sont liées à l'inventaire des ressources forestières et aux données sur la croissance et le rendement des peuplements. L'importance accrue qui est mise sur ces deux aspects ne signifie pas que les autres questions (succession des peuplements, perturbations naturelles, changement climatique et effet des guides) sont sans importance.

Voici, classées par ordre d'importance, les cinq choses que nous considérons comme nécessitant le plus d'amélioration :

1. Il faut améliorer les liens entre l'inventaire des ressources forestières et les données sur la croissance et le rendement des peuplements (on pourrait notamment concevoir une méthode pour mettre les deux variables en corrélation et confirmer les résultats; on pourrait aussi améliorer les méthodes employées pour attribuer des courbes de croissance et de rendement aux peuplements relevés dans l'inventaire des ressources forestières).

2. Il faut avoir des données plus réalistes pour prédire les stages de succession au sein des peuplements.

3. Il faut avoir des courbes de croissance et de rendement supplémentaires pour les peuplements plantés et ceux qui sont reconstitués naturellement.

4. Il faut actualiser plus souvent l'inventaire des ressources forestières.

5. Il faut avoir de meilleures données sur les facteurs touchant la productivité des terrains (p. ex., humidité du sol et régimes d'enrichissement), et inclure celles-ci dans les modèles de croissance et de rendement.

Pour élaborer un plan visant à diminuer l'incertitude des prévisions, nous proposons les trois mesures suivantes. Il faut d'abord décrire clairement chaque question. Deuxièmement, il faut établir une liste des travaux (en cours ou commencés récemment) qui sont en rapport avec les besoins liés à la prédiction des volumes de bois exploitables en Ontario. Troisièmement, il faut évaluer la liste pour déterminer la vitesse à laquelle les besoins peuvent être abordés, les dépenses que cela nécessiterait et la mesure dans laquelle les prévisions seraient améliorées. Nous pourrons ainsi établir une liste de priorités à partir de laquelle nous pourrons élaborer un plan d'action.

Acknowledgements

We received valuable assistance and advice from many people for this project. Jim Baker's support helped us to obtain funding for this project from the Science Advisory Team of the Ontario Ministry of Natural Resources (MNR). Fraser Dunn, Director of Applied Research and Development Branch, provided funding for the *Art and Science of Wood Supply Estimation Workshop*. The management team at the Ontario Forest Research Institute (at the time consisting of Wayne Fiset, Vivienne Scott, and Mark Parsons) enabled us to obtain an intern position that was focused on this project. Reviews of this report at various stages in its development were provided by Frank Addante, Jim Baker, Lisa Buse, Joe Churcher, Michael Gluck, Gord King, Jorma Paloniemi, Murray Radford, and Jim Rice, all with MNR. We also thank Wayne Fiset, Dave Hayhurst, Peter Henry, Dirk Kloss, Thom McDonough, Abigail Obenchain, Bill Parker, and John Parton, all with MNR, for their contributions to various components of this project. Finally, we are grateful to Tom Erdle, Robert Wagner, and Gordon Weetman for their keynote presentations at the *Art and Science of Wood Supply Estimation Workshop*.

Contents

Executive Summary i

Acknowledgements ii

Introduction 1

Wood Supply Prediction in Other Jurisdictions 1

Quebec 1

British Columbia 2

Wood Supply Prediction in Ontario 3

Identifying Sources of Uncertainty in Ontario's Wood Supply Prediction 5

Survey objectives and approach 5

Survey results 6

Workshop objectives and approach 7

Workshop results 8

Discussion 9

Conclusions and Recommendations 10

References 12

Appendix 1. Example of a sensitivity analysis conducted for the Lillooet timber supply area in British Columbia 13

Appendix 2. Wood supply themes and sub-themes that were ranked by survey participants for importance as uncertainties in wood supply estimates 14

Appendix 3. Results of sub-theme rankings from survey responses 16

Appendix 4. Prioritized results of a workshop to identify research and science needs to address uncertainty in wood supply estimation 20

Introduction

Achieving the objectives of healthy ecosystems and sustainable forest resources is a challenge requiring sound management planning. Forest modelling techniques help predict the economic, social, and environmental results of forest management options before management plans are finalized. Estimating future wood supply is a key economic component of this planning process. To ensure that demand for wood for forest industry is given appropriate consideration during the forest management planning process, while maintaining the core principle of forest sustainability, the *Ontario Wood Supply Strategy* was developed. This strategy identifies critical wood supply issues and provides approaches to address them (OMNR 2004a).

Wood supply estimates cannot be perfectly accurate because of the complexity of forest ecosystems and uncertainties in the information used in management planning. The accuracy of wood supply predictions relies in large part on the quality of inventory and yield data, as well as assumptions made in their use. Predictions also depend on the assumptions and methods in the timber supply model that those data are applied to, which in Ontario is primarily the Strategic Forest Management Model (SFMM). Estimating confidence intervals for all input data and understanding related assumptions in SFMM are major undertakings that are beyond current technical capabilities.

Thus, the objectives of this project are to identify and prioritize uncertainties in forest data and modelling based on their relative effects on wood supply prediction, and recommend methods to address them. This information could help the Ministry of Natural Resources (MNR) to focus efforts on areas of greatest relevance and highest effect to reduce uncertainty. It could also allow model developers and users to address uncertainties in order of importance in an effort to increase confidence in wood supply predictions.

We consider uncertainty to be information (data and assumptions) for which confidence intervals have not been quantified. To carry out this project we drew extensively upon the expert opinions of forestry specialists in Ontario to identify factors contributing large sources of uncertainty.

In the report, we first review efforts in other jurisdictions to address uncertainty in wood supply prediction. Second, we present current methods of wood supply prediction in Ontario followed by the methods and results of a survey and subsequent workshop to identify issues creating uncertainty in wood supply prediction. Finally, the results are synthesized and prioritized and an action plan is proposed to address uncertainty in wood supply prediction in Ontario in a logical and effective manner.

Wood Supply Prediction in Other Jurisdictions

Uncertainty in wood supply estimation is not unique to Ontario. An investigation of other regions of Canada revealed that two in particular have attempted to address this issue: Quebec and British Columbia. We summarize here the approaches used in Quebec and BC to improve the accuracy of their wood supply estimates.

Quebec

Forest management planning and wood supply estimation in Quebec are governed by Quebec's *Forest Act (Loi sur les Forêts)* (MRNFP 2001) and the *Forest Management Planning Manual (Manuel d'Aménagement Forestier)* (MRNFP 2003). Annual allowable cut is determined using forest inventory information and yield curves in a wood supply simulation model called SYLVA II, which compares scenarios and forest management alternatives (CCFM 2005). The area of timber harvest on public lands in Quebec is divided into 114 forest management units. Annual allowable cut is redetermined every five years using updated management assumptions, available volume, changes in management policy, and improvements in growth models.

In 2003, a scientific committee examined Quebec's procedures for determining annual allowable cut. This exercise, the first of its kind in Quebec (and perhaps in Canada), explored the sensitivity of annual allowable cut to forest inventory and growth models. An estimate of error associated with wood supply predictions was obtained using the bootstrap resampling method. The analysis showed that predictions overestimated the volume for spruce-pine-fir-larch (*Picea* spp.-*Pinus* spp.-*Abies* spp.-*Larix* spp.) forests and underestimated the volume of mixed conifer and poplar (*Populus* spp.) forests (MRNFP 2004).

Error in growth curves for naturally regenerated stands was estimated using data from a network of 12,000 permanent sample plots for which repeated volume measurements were available (Pothier and Savard 1998). The prediction error was estimated by subtracting predicted volume based on growth curves from actual measured volume. Stand age, site index, and stocking were identified as the most important sources of error in volume prediction. For tolerant hardwood forests, bias in model predictions increased with stand age and volume and there was a tendency to underestimate volumes in young stands with low volumes and to overestimate volumes in older stands with higher volumes. Volume estimates tended to be unbiased in middle-aged, mid-volume stands. Fewer measurements were available for growth curves in plantations, and among those that did exist, more data was available for young stands. Bias was almost zero when data for four species in plantations were combined (black spruce (*Picea mariana* (Mill.) B.S.P.), white spruce (*Picea glauca* (Moench) Voss), Norway spruce (*Picea abies (L.) Karst.*) and jack pine (*Pinus banksiana Lamb.*)).

Most sources of uncertainty in Quebec's wood supply estimation were related to forest resources inventory data and growth models. Wood supply estimation was very sensitive to post-renewal succession assumptions (MRNFP 2004).

The committee recommended the following improvements in Quebec's wood supply estimation practices:

- Develop methods to quantify error related to wood supply estimation inputs and the propagation of error through the estimation process
- Revise sampling design and forest inventory estimafors according to recent sampling theory
- Conduct sensitivity analysis as part of each wood supply prediction[1]
- Conduct research to improve the modelling of forest succession, stand growth, and natural disturbance (MRNFP 2004)

British Columbia

Timber supply analysis in British Columbia is performed for each of 37 timber supply areas (equivalent to Ontario's forest management units). The choice of timber supply model is left to the discretion of planning teams (BCMOF 2003). In the past the models used have included the Forest Planning Studio, the Forest Service Simulator, and the Forest Simulation Optimization System. A "base case" is established for each timber supply area using data describing the forested land base (e.g., ages and species composition of stands), forest dynamics, and management practices. Using these data and a simulation of forest growth, harvest, and natural events, a series of timber supply forecasts is produced. One of these forecasts is chosen to avoid excessive changes or shortages in timber supply.

British Columbia deals with uncertainty in timber supply in two ways. First, a sensitivity analysis is used to examine the range of possible results from the base case to minimize risk to both the environment and timber supply. This is done by considering how specific uncertainties in the data and assumptions affect the results (BCMOF 2004; BCMOF 2005). Common sensitivity analyses used in British Columbia include modifying the timber harvesting land base, stand timber yields, site productivity, and minimum harvestable ages. Appendix 1 provides an example of the results of a sensitivity analysis performed for the Lillooet timber supply area in British Columbia. The second way uncertainty in BC's timber supply prediction is dealt with is to re-determine the annual allowable cut at least every five years, so that predictions are based on up-to-date data, management assumptions, and policies (Snetsinger 2005).

[1]More information on sensitivity analysis is provided in the section on wood supply prediction in Ontario.

Wood Supply Prediction in Ontario

Forest management planning in Ontario follows requirements set out in the *Forest Management Planning Manual* (OMNR 2004b) and the *Forest Information Manual* (OMNR 2001). Figure 1 provides an overview of steps required to produce management plans in the Area of the Undertaking (the portion of Ontario in which Crown forests are managed for commercial timber). In most cases wood supply is estimated using the Strategic Forest Management Model (SFMM), although other wood supply models are occasionally used. As is the case in other jurisdictions, the timber supply model makes predictions based on information from stand inventory and assumptions about forest growth and succession, silvicultural treatments, and management objectives (Kloss 2002).

Stand inventory describes forest types and their areas. This inventory is obtained from aerial photographs that are interpreted by trained personnel to describe stand area, tree species composition, age, height, site class, and other stand attributes. *Forest units* are aggregated from stands composed of similar species, which developed in a similar manner (i.e., either naturally or in response to silvicultural treatment) and are managed under the same silvilcultural system. Forest units are the basic element used in forest management planning and wood supply prediction.

Forest management planning is an uncertain activity for many reasons, including the variability inherent in natural systems, the long time frames involved, and the necessity of using information based on either small samples or remote sensing. In Ontario, this uncertainty is dealt with in two ways. One is to re-estimate wood supply regularly (minimum of every five years). The second is to use a step-wise construction of SFMM, by defining management objectives, performing sensitivity analysis of components, and conducting a preliminary scoping analysis.

Sensitivity analysis assesses how uncertainty in the output of a model can be divided among the various model inputs (Saltelli et al. 2004). However, while applying sensitivity analysis to wood supply predictions in Ontario is appealing, its feasibility here is constrained by two factors:

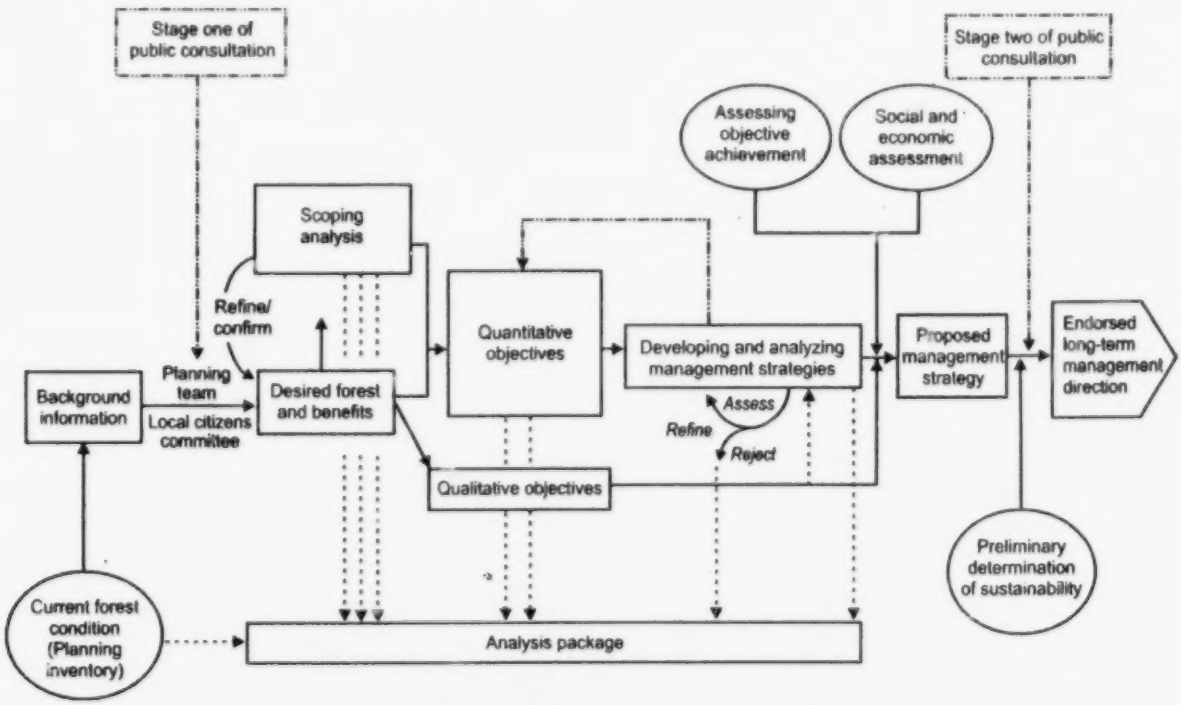

Figure 1. *Forest management planning procedure described in Ontario's Forest Management Planning Manual (from OMNR 2004b).*

1. Wood supply prediction relies on too many inputs to perform rigorous sensitivity analysis of them all. This is why sensitivity analysis of wood supply predictions in British Columbia is reduced to a simple one-at-a-time manipulation of a subset of key input variables, with variables increased or decreased by 10% of their estimated value. The value of such analysis is limited because it does not account for the interaction of input variables or for possible compensating effects they may have.

2. More importantly, the primary wood supply prediction model (SFMM) in Ontario is an optimization model. The model's optimization methodology means that it varies numerous objectives while maximizing wood supply after first setting aside sufficient area to satisfy other management requirements (e.g., wildlife habitat). Thus, the effect of changing an input variable to test its effect on wood supply prediction is often compensated for as the model independently and in an unspecified order and manner varies other objectives. In addition, SFMM often produces "tight" predictions, so that altering an input variable without adjusting other management options can prevent the model from converging to a feasible solution.

While estimating variation in model outputs in response to changes in input variables and model parameters is an important part of a sensitivity analysis, the main goal is to ensure that model predictions are close to the actual values of predicted variables. In other words, the accuracy of model predictions (model validation) is more important than model precision (sensitivity analysis). Once it is established that model predictions are on average unbiased, the next step is to reduce variation in model output through reducing uncertainty in input variables and parameters.

Although sensitivity analysis may not be a suitable approach for assessing wood supply predictions in Ontario, the idea of apportioning uncertainty in these predictions to uncertainty in model inputs is still valid; i.e., changes in input data and SFMM parameters may substantially affect predicted values. Figure 2, for example, shows the results of two hypothetical SFMM simulations conducted for an Ontario forest management unit, in which the yield curves were increased and decreased by 10%. In this case, 10% change in yield curves resulted in up to a 25% change in predicted wood volume. These results indicate the potential value of looking at how error in input variables affects predicted wood supply.

We used an expert opinion-based approach to assess uncertainties in Ontario wood supply predictions, which may indicate SFMM input variables to test in a sensitivity analysis, as well as other approaches to addressing this issue.

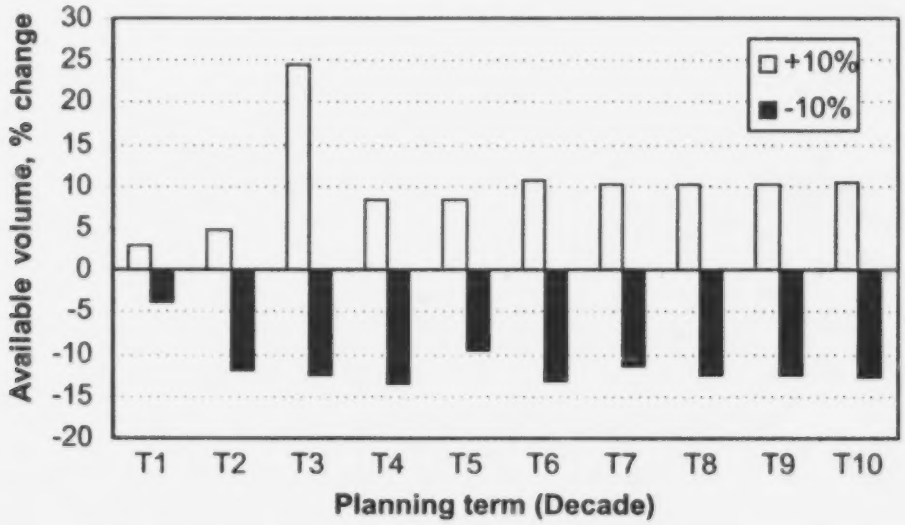

Figure 2. *Percent change in predicted wood volume in response to 10% increase (light bars) or decrease (dark bars) in available timber yield.*

Identifying Sources of Uncertainty in Ontario's Wood Supply Prediction

We used an e-mail survey and a workshop to identify areas that could be improved to obtain more reliable estimates of wood supply. Both processes sought the opinions of forestry specialists in government and forest industry.

Survey objectives and approach

In the fall of 2005, a survey was undertaken to rank a predetermined list of issues thought to affect wood supply estimation. The survey provided a preliminary evaluation that refined our focus in preparation for a subsequent workshop on the topic. The survey was intended to identify sources of uncertainty that affect wood supply prediction — these may differ from factors that affect wood supply.

Factors creating uncertainty in wood supply prediction are linked closely to forest management planning. Therefore, survey questions reflected the fact that Ontario does most of its wood supply prediction using SFMM. An overview of how wood supply is predicted in Ontario using SFMM is shown in Figure 3. The process of wood supply analysis has as its ultimate objective a socio-economic goal, which is generally achieved by maximizing the supply of wood given other socio-economic and ecological constraints. (Although the impact of climate change on wood supply is not modelled in SFMM, it may affect future rates of natural disturbance, forest succession and growth curves, and is included in Figure 3.) The area inside the dotted box in Figure 3 shows factors included in SFMM. The model is affected by socio-economic factors that determine the amount of land set aside for non-timber uses. The wood supply model is run repeatedly, producing preliminary woood supply predictions. When an acceptable balance between timber and non-timber

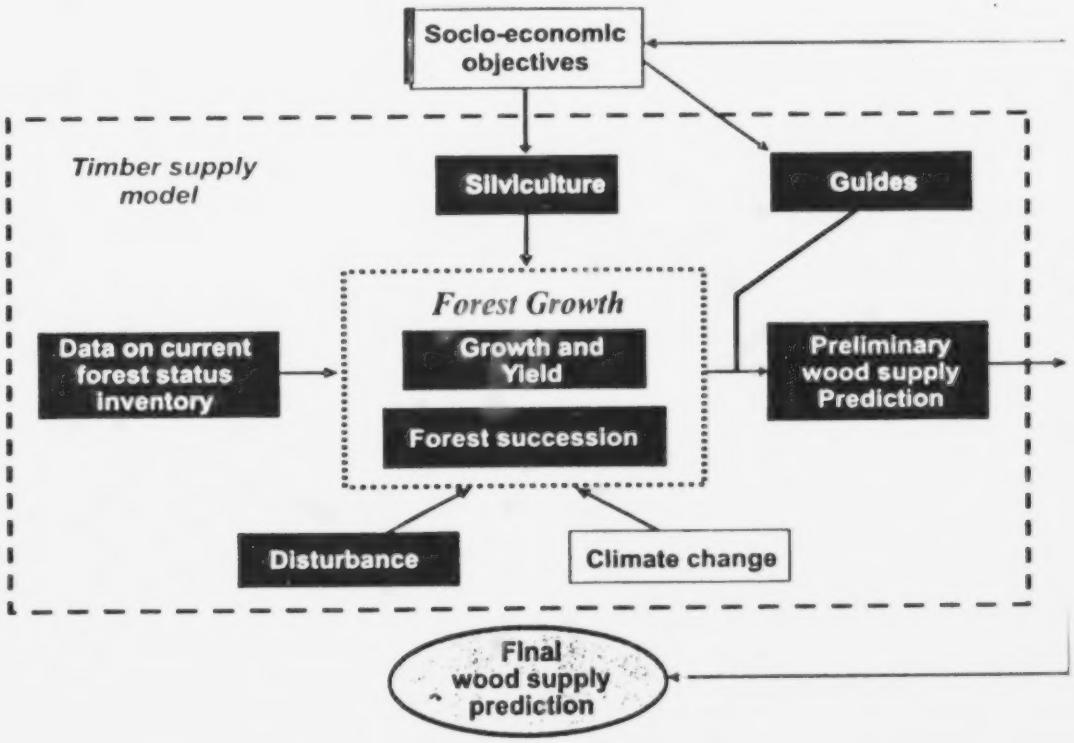

Figure 3. *An overview of factors considered in wood supply prediction. Components outside the dashed box indicate the goals and objectives of wood supply prediction. Components inside the dashed and dotted boxes indicate data and processes required to predict wood supply. Climate change is expected to have a substantial effect on future wood supply but is not yet accounted for in Ontario's wood supply predictions. Arrows show the flow of data and assumptions.*

values is reached, a final wood supply prediction is produced. Wood supply, which is an output of the model, is a socio-economic objective that is derived after non-wood supply objectives are satisfied.

The survey themes reflected the main components of wood supply prediction shown in Figure 3. The questionnaire requested rankings on nine themes:

- Forest resources inventory
- Growth and yield
- Effects of silviculture (on growth and yield)
- Forest succession
- Natural disturbance by wildfire
- Natural disturbance by insects
- Other natural disturbances
- Climate change and exotic species, and
- Effects of guides (i.e., uncertainty in the amount of wood unavailable for harvest as a result of meeting guide objectives).

Each theme was divided into a number of sub-themes. Respondents ranked themes and sub-themes (Appendix 2) using a four-point scale, ranging from very low importance (1) to very high importance (4). To compare survey results among organizations, respondents were asked to describe their affiliation as well as their present and past involvement in wood supply prediction.

The survey was distributed electronically to organizations employing specialists in wood supply planning within MNR and forest industry. We debated whether to send the survey to a select group of "experts" (identified based on their work position) *versus* a broader list that might include those who have not had extensive experience in wood supply issues. There were risks with either course of action: Using a select group we could miss some important contributors who may have previously worked in wood supply prediction. Using a broader list we increased the risk of biasing the survey by obtaining some less "informed" responses. In the end, we opted to survey a broader list of recipients, leaving it to the recipient's judgement whether they were qualified to respond. The responses we received vindicated this course of action, as many recipients filled out only a portion of the questionnaire indicating that they did not feel qualified to rank all themes.

Rankings of themes and sub-themes were analyzed using frequencies and percentages. Comments and new themes identified by respondents were enumerated but not ranked.

Survey results

In total, 97 people responded to the survey (Table 1). We were satisfied with this response rate, given that participation was voluntary and the survey was somewhat long and complex. In addition to those providing rankings, 5 respondents commented without providing rankings. Among the 92 respondents who ranked themes, 54 were forest management planning specialists, 15 were forest scientists, 6 were forest resources inventory specialists, 3 were forest policy developers and 14 were specialists in other areas, including silviculture and SFMM modelling. Of the respondents providing rankings, 13% were from forest industry, and 87% from the government.

More than 60% of respondents identified forest resources inventory, growth and yield, forest succession and the effects of silviculture as significant contributors to uncertainty in wood supply prediction (Figure 4). However, even the lowest-ranked themes were credited with creating a high level of uncertainty in wood supply prediction by close to one-third of respondents.

MNR staff ranked many issues differently than their forest industry counterparts (Figure 5). Government staff rated growth and yield, climate change and exotic pests, and other disturbances much higher than industry staff. In contrast, forest industry respondents identified forest resources inventory, forest succession, and the effects of guides as greater sources of uncertainty in wood supply estimation than government respondents.

The ranking of sub-themes also yielded interesting results, detailed in Appendix 3. However, we could not rule out bias in these rankings since survey respondents were only able to rank issues we provided. Therefore, there is a risk that some important issues might have been missed by the survey. We felt these would be revealed during the workshop.

Table 1. *Organizational affiliations of wood supply prediction survey respondents.*

Government		Forest industry	Total
Research	Planners and others		
15	70	12	97

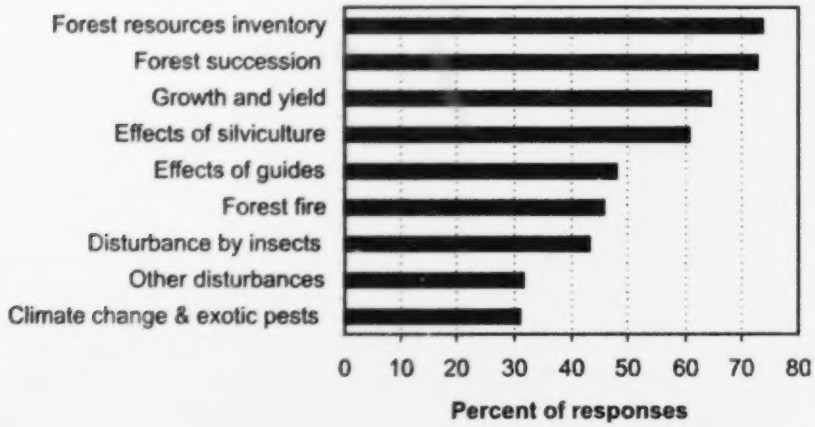

Figure 4. *Percentage of all survey responses indicating themes that are high or very high sources of uncertainty in wood supply prediction.*

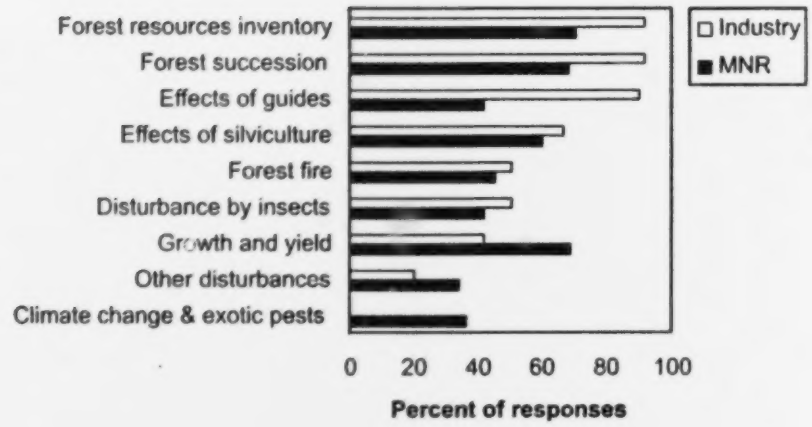

Figure 5. *Percentage of all survey responses from MNR and forest industry staff indicating themes that are high or very high sources of uncertainty in wood supply prediction.*

Workshop objectives and approach

The workshop on sources of uncertainty in wood supply prediction was an opportunity for specialists from MNR, industry, consulting companies, universities, and the Canadian Forest Service to directly discuss issues affecting wood supply prediction. In total, 78 people took part in the workshop held in Sault Ste. Marie on December 13, 2005. Input from participants was obtained in a two-step process. In the first step, participants were asked to identify the issues creating uncertainty in wood supply estimation in each of six predetermined themes:

- Forest resources inventory
- Growth and yield
- Forest succession
- Natural disturbance
- Effects of guides
- Climate change and exotic species.

In the second step, participants ranked issues identified in step one. A two-stage ranking occurred. First, participants ranked issues based on their perceived priority within themes. Second, each participant identified their overall top five issues, among all themes.

Workshop results

Workshop participants identified a total of 155 issues affecting wood supply prediction. This list was condensed to a more digestible form by combining similar issues that appeared under different themes and removing issues focussed on non-analytical aspects of wood supply (e.g., policy, implementation of guides). The resulting list of 43 issues is presented in order of descending priority (as ranked by participants) in Appendix 4. Most of the issues (18) were related to growth and yield and forest resources inventory. The top 10 ranked issues in order of priority were:

1. Create a stronger linkage between forest resources inventory and growth and yield data.

This issue encompassed a number of sub-issues, such as developing a method to calibrate/validate one with the other, improving methods of assigning growth and yield curves to stands in forest resources inventory, and spatially extrapolating growth and yield curves from plot- to forest-level. The overriding concern raised by workshop participants was that forest resources inventory and growth and yield programs exist as separate and independent entities, with insufficient efforts to ensure compatibility of methods and results produced by the two programs.

2. Produce more realistic succession information by developing approaches and obtaining data to predict and validate successional changes at various stages of stand development.

Examples identified by participants where better successional information is needed include:

- Early stage (post-renewal) succession
- Conversion of naturally regenerating stands from conifer to mixedwood
- Intermediate stage (incremental) succession (i.e., succession occurring between free-to-grow and stand maturity)
- Late stage (terminal) succession (i.e., occurring at stand break-up)

Information on succession was deemed inadequate at both the forest and stand level. At the forest level, a lack of sufficient information at each successional stage of forest development was raised as a major source of uncertainty. The current deterministic and non-spatial description of succession was also raised as a source of uncertainty in wood supply predictions. At the stand level, prediction of successional changes needs to include changes in stand attributes, such as stocking.

3. Create additional growth and yield curves for planted and naturally regenerated stands.

This issue focussed on the lack of both species/forest unit-specific and region-specific growth and yield curves, resulting in the use of generic curves that can under- or over-estimate growth.

4. Update forest resources inventory more frequently.

This source of uncertainty was attributed to infrequent forest resources inventory updates (20 year cycle), resulting in overly-long extrapolations of forest resources inventory data.

5. Develop better data on factors affecting site productivity (e.g., soil moisture and nutrient regimes) and include these factors in growth and yield models.

Although this issue appears similar to #3, it focussed on a different source of uncertainty, namely, on the lack of "ecological" context in the use of growth and yield curves. While participants stopped short of articulating a need for more process-based growth and yield curves, the issue essentially points in this direction, i.e., moving from empirical curves to those that account for ecological factors affecting site productivity.

6. Incorporate an economic analysis of wood supply in forest management planning to differentiate wood supply based on cost (i.e., cost of wood to the mill).

Strictly speaking, this issue points not to a source of uncertainty but to a deficiency in wood supply prediction, i.e., the importance of predicting the cost-feasibility of harvestable wood, rather than just its availability. However, it is included since many workshop participants felt that this issue seriously affects the accuracy of wood supply prediction. It also relates to an issue raised frequently, namely the current non-spatial approach to wood supply prediction (since adequate economic analysis is impossible without spatially explicit identification of wood sources).

7. Implement better statistical design for sampling and validating data in forest resources inventory.

This issue resulted from combining a number of sub-issues, all of them revolving around the need to develop a better sampling design and collect

more data to produce and validate forest resources inventory.

8. Evaluate forest management guides to determine if they are meeting their objectives (through effectiveness monitoring), if they are being properly applied (compliance monitoring), and if they are having predicted effects (on non-target values) (effects monitoring).

This issue encompasses two major needs:

(a) to improve the science supporting the guides (e.g., increase confidence in the minimum required allocation of land to wildlife habitat), and

(b) to ensure that guides *are working* (e.g., land base allocated to wildlife protection results in desired effect on wildlife population levels).

A number of guide-related issues were evidently related not to the guides *per se* but to their implementation. Interestingly, participants expressed a wide range of opinion on the desired flexibility of guide implementation, from *make them very strict* to *make them as flexible as possible*, the latter indicating allowing room to manoeuvre when allocating land required by guides. While these are undoubtedly important issues affecting wood harvest, they were removed from the list of issues as they are not sources of uncertainty in wood supply prediction.

9. Identify the influence of climate on forest insect pest populations (both introduced and exotic pests).

A number of sources of uncertainty induced by climate change were raised at the workshop; however, the one that appeared to resonate with participants the most was changes in forest insect populations and their impact on wood supply. Other climate change effects (e.g., on forest succession, natural disturbances) received low or no ranking, and are presented in Appendix 4.

10. Improve the prediction of silviculture effects on forest productivity.

Different yield curves are used for planning based on the level of silvicultural intensity applied in the management plan; however, there is uncertainty about which yield curve is appropriate for given scenario. This issue is related to issue #3, but participants emphasized that it needed to be listed separately.

Discussion

A review of wood supply estimation procedures in Ontario, British Columbia, and Quebec revealed similarities in approaches to dealing with uncertainty. All three provinces re-plan frequently to reduce the effect of changing conditions and incorporate improved knowledge of wood supply estimation. Only British Columbia incorporates sensitivity analysis to assess how wood supply changes with the accuracy of data used in wood supply models. However, sensitivity analysis was also recommended for Quebec by a scientific committee established to evaluate wood supply estimates in that jurisdiction.

When we asked local SFMM modelling experts whether sensitivity analysis had been considered for Ontario, they indicated that since SFMM attempts to satisfy numerous objectives simultaneously, sensitivity analysis could not be used in the true sense (i.e., it would be impossible to hold other factors constant while varying one for sensitivity testing). In addition, sensitivity analysis is somewhat inappropriate since, during the planning process, the planning team may vary factors to achieve management objectives. However, while SFMM and the planning process may preclude conducting a true sensitivity analysis, there is nevertheless value in determining the effect on timber supply of varying factors based on a range of potentials errors. When we undertook this form of analysis we found considerable variation in the volume of timber available for harvest (Figure 2).

The survey and workshop carried out in this project were complementary exercises that resulted in a prioritized list of factors affecting uncertainty in Ontario's wood supply predictions. The survey provided a valuable overview of factors creating uncertainty in wood supply estimates. The high response rate indicates that this issue is considered important and that people concerned with wood supply want the uncertainties reduced. In addition, respondents provided valuable feedback about the way in which the survey was prepared and distributed and identified additional issues they thought were relevant to estimating wood supply accurately.

MNR and forest industry respondents ranked some themes very differently. While this may reflect an anomaly due to the relatively low participation by forest industry in the survey (only 12 respondents), it could also indicate that real differences exist between

these groups. Further investigation of this issue is warranted. While the survey made it possible to compare results among specialists and organizations, it allowed no interaction among respondents. This shortcoming was addressed in the subsequent workshop.

Only 18 of 78 workshop participants also took part in the survey, so the workshop was an avenue for a different group of specialists to provide input. This, plus the less structured approach to identifying issues used in the workshop, likely explains differences between workshop and survey results. The workshop created a venue for discussions and allowed participants to rank issues identified by others. A drawback of the workshop approach was that it did not allow comparison of the results between participating groups (e.g., government vs. industry). However, in our monitoring of discussions during the workshop, it was clear that differences exist in how MNR and industry experts view some issues.

It is not surprising that many issues related to forest resources inventory and growth and yield were identified as important sources of uncertainty in wood supply estimation since these are the principal data source used in wood supply modelling. Similarly, since SFMM is the primary modelling tool used to predict future harvest rates, issues around SFMM modelling were predictably identified as important. For example, stronger integration between the forest resources inventory and growth and yield was called for, such as by developing an ability to calibrate/ validate one with another. Also, the need to link forest succession with growth and yield models was deemed important. Areas in which SFFM could be improved include adding a spatial analysis to model natural disturbances and accounting for natural disturbances other than wild fire.

The survey and workshop both indicated that issues related to forest resources inventory were of most concern. While both exercises identified issues related to growth and yield as important sources of uncertainty for wood supply prediction, in the survey the succession theme ranked above growth and yield and nearly as high as forest resources inventory. In comparison, in the workshop succession ranked below growth and yield in importance and received a relatively low ranking.

The relative importance of natural disturbance, guides, and climate change/exotic insects was on average higher in the survey than in the workshop. We believe this reflects the way in which ranking occurred. In the survey, any number of themes could be ranked as being highly important, regardless of how other themes were ranked. In the workshop, participants could assign importance to a limited number of themes. This undoubtedly focused voting in the workshop towards what people thought were the most important themes, with the result that relatively less important themes attracted fewer votes.

The much higher importance placed on forest resources inventory compared to other themes should not prevent other themes being addressed. Specific issues within lower ranked themes will undoubtedly have a greater impact on uncertainty in wood supply prediction than some issues in forest resources inventory. The survey and workshop were used to identify issues, but were not designed to identify the most effective order in which to address the issues.

Conclusions and Recommendations

Through our interactions with people involved in forest management planning and wood supply prediction we learned that they believed strongly in the need to make reliable and accurate predictions of wood supply, as it is one of the key tools of sustainable forest management. With their help, we identified the following top 10 areas related to wood supply prediction that need improvement:

1. Create a stronger linkage between forest resources inventory and growth and yield data.
2. Produce more realistic succession information by developing approaches and obtaining data to predict and validate successional changes at various stages of stand development.
3. Create additional growth and yield curves for planted and naturally regenerated stands.
4. Update forest resources inventory more frequently.
5. Develop better data on factors affecting site productivity (e.g., soil moisture and nutrient regimes) and include *these factors* in growth and yield models.
6. Incorporate an economic analysis in forest management planning to differentiate wood supply based on cost (e.g., cost of wood to the mill).
7. Implement better statistical design for sampling and validating data in forest resources inventory.

8. Evaluate forest management guides to determine if they are meeting their objectives (through effectiveness monitoring), if they are being properly applied (compliance monitoring), and if they are having predicted effects (on non-target values) (effects monitoring).
9. Identify the influence of climate on forest insect pest populations (both introduced and exotic pests).
10. Improve the prediction of silviculture effects on forest productivity.

To address these issues we propose the following steps be taken: First, clearly describe each issue. Second, compile a list of ongoing projects addressing the areas that need improvement. Third, evaluate the assembled lists to assess the speed with which the issues can be addressed, the cost to address them, and the degree to which wood supply estimates would be improved once addressed (Figure 6). The latter step may require some form of sensitivity analysis to evaluate expected improvements in wood supply estimates (keeping in mind the limitations of sensitivity analysis using SFMM). This exercise may entail an assessment of the risk to wood supply if improvements are not made. The result of this process will be a prioritized list of issues ranked by impact on reducing wood supply estimate uncertainty and cost. This list would provide an objective basis for addressing this important forest management need.

In conclusion, the long term health of the province's forest industry relies on a dependable and predictable wood supply. Sustainability requires good management planning. This report identifies improvements in data and models that will contribute to Ontario's vision of sustainable development and the mission of ecological sustainability, described in *Our Sustainable Future*, MNR's strategic directions document (OMNR 2005).

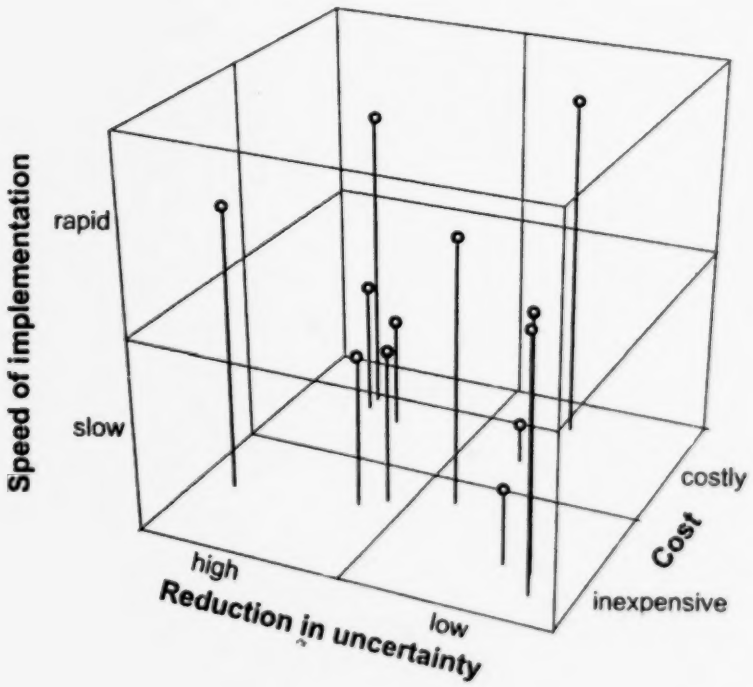

Figure 6. *Selection criteria that could be used to evaluate which areas to focus on to address uncertainties in wood supply estimates. Each point represents an area under consideration. The selection process would favour study areas that could be completed and implemented quickly effecting a high reduction in uncertainty at low cost.*

References

[BCMOF] British Columbia Ministry of Forests and Range. 2003. DFAM timber supply review – technical information sheet. Ministry of Forests and Range. Victoria. BC. 9 p.

[BCMOF] British Columbia Ministry of Forests and Range. 2004. Interim standards for data package preparation and timber supply analysis. Defined Forest Area Management Initiative. Ministry of Forests and Range. Victoria, BC. 21 p.

[BCMOF] British Columbia Ministry of Forests and Range. 2005. Timber supply analysis standards for innovative forest practices agreements. Ministry of Forests and Range. Victoria, BC. 9 p.

Brown, C.G. 2005. Lillooet Timber Supply Area. Timber supply review #3. Analysis report. Ministry of Forests and Range. Victoria, BC. 152 p.

[CCFM] Canadian Council of Forest Ministers. 2005. Wood supply in Canada: 2005 Report. National Forestry Database Program. Ottawa, ON. 44 p.

Kloss, D. 2002. Strategic forest management model version 2.0 user guide. Ont. Min. Nat. Resour., Toronto, ON. 264 p.

[OMNR] Ontario Ministry of Natural Resources. 2005. Our sustainable future. Ministry of Natural Resources. Queen's Printer for Ontario, Toronto, ON. 29 p.

[OMNR] Ontario Ministry of Natural Resources. 2004a. Provincial wood supply strategy. Ministry of Natural Resources, Queen's Printer for Ontario, Toronto, ON. 92 p.

[OMNR] Ontario Ministry of Natural Resources. 2004b. Forest management planning manual. Ministry of Natural Resources, Queen's Printer for Ontario, Toronto, ON. 442 p.

[OMNR] Ontario Ministry of Natural Resources. 2001. Forest information manual. Ministry of Natural Resources. Queen's Printer for Ontario. Toronto, ON. 400 p.

Pothier, D. and Savard, F. 1998. Actualisation des tables de production pour les principales espèces forestières du Québec. Ministère des Ressources Naturelles du Québec, Québec. 183 p.

[MRNFP] Québec Ministère des Ressources Naturelles, de la Faune et des Parcs. 2001. Loi sur les forets. Bibliothèque nationale du Québec, Québec.<http://www2.publicationsduquebec.gouv.qc.ca/dynamicSearch/telecharge.php?type=2&file=/F_4_1/F4_1.html>. Accessed January 2006.

[MRNFP] Québec Ministère des Ressources Naturelles, de la Faune et des Parcs. 2003. Manuel d'aménagement forestier. 4e édition. Bibliothèque nationale du Québec, Québec. 245 p.

[MRNFP] Québec Ministère des Ressources Naturelles, de la Faune et des Parcs. 2004. Rapport du comité scientifique chargé d'examiner le calcul de la possibilité forestière. Ministère des Ressources Naturelles, de la Faune et des Parcs, Québec. 280 p.

Saltelli, A., Tarantola, S., Campolongo, F., and Ratto, M.. 2004. Sensitivity analysis in practice. A Guide to Assessing Scientific Models. John Wiley & Sons, New York, NY. 232 p.

Snetsinger, J. 2005. Rationale for annual allowable cut (AAC) determination. Strathcona timber supply area. Ministry of Forest and Range, Victoria, BC. 71 p.

Appendix 1. Example of a sensitivity analysis conducted for the Lillooet timber supply area in British Columbia (Brown 2005)

Attribute	Analysis Performed	Result (harvest volume level)
Land base	+ 10%	• Annual allowable cut is maintained for 2 additional decades • No change in the mid term • 11.6% increase in the long term
	- 10%	• Annual allowable cut is maintained for 2 fewer decades • Transition to LTHL occurs 2 decades earlier • 9.7% decrease in the long term
Stand yields	+ 10%	• Annual allowable cut is maintained for 2 additional decades • Transition to LTHL occurs 2 decades later • 3.2% increase in the long term
	- 10%	• Annual allowable cut is maintained for 2 fewer decades • Transition to LTHL occurs 1 decade earlier • 3.9% decrease in the long term
Minimum harvest ages	+ 10 years	• Annual allowable cut maintained for 1 less decade • No change in the mid term • 0.5% increase in the long term
	- 10 years	• No change in the short term • No change in the mid term • 0.8% decrease in the long tern
Harvest priorities	Change to "absolute oldest first" from "relative oldest first"	• No change in the short term • No change in the mid term • 2.9% decrease in the long term

Appendix 2. Wood supply themes and sub-themes that were ranked by survey participants for importance as uncertainties in wood supply estimates

Theme	Sub-theme
Forest resources inventory	• Stand area • Species composition • Stand age • Stand height • Site class (site productivity) • Barren and scattered land
Growth and yield	• Stocking • Cull factors • Net down factors other than cull • Timing and rate of stand break-up • Unmerchantable species • Wood quality (value derived from harvested volume) • Number of plots for each forest type/site class
Effects of silviculture on growth and yield	• Success rate of planting (e.g., achieving acceptable stocking and free-to-grow within desired time frame) • Uncertainty around growth response to tending • Variability of growth response to pre-commercial thinning • Uncertainty around growth of stands regenerated using the Careful Logging Around Advanced Growth (CLAAG) system • Difference between potential and actual yield curves using genetically improved stock
Forest succession	• Occurrence (timing) of successional transitions from one species group to another • Proportion of stands succeeding from one species group to another • Difference between succession following harvest and natural disturbance
Natural disturbance by wildfires	• Return interval • Frequency (number of individual fires within a given area during a given period of time) • Burning likelihood related to other disturbances (e.g., insects, wind) • Year-to-year variation in area burned • Effect of non-stand replacing fires • Burning likelihood related to age class • Burning likelihood related to species • Extent (size of an individual fire)

Theme	Sub-theme
Natural disturbance by insects	• Area affected by spruce budworm • Area affected by jack pine budworm • Effect of insect outbreak on forest succession • Return interval • Extent (area of insect outbreak) • Year-to-year variation in area affected by insect outbreak • Effect of insect outbreak on growth and yield • Area affected by forest tent caterpillar
Other natural disturbances	• Area affected by disturbance • Disturbance return interval • Year-to-year variation in area affected by disturbance • Effect of disturbance on growth and yield • Effect of disturbance on forest succession
Climate change and exotic species	• Altered growth rates and yields • Loss of genetic gains due to altered climate • Frequency and intensity of fire • Introduction of non-native pests • Planting of new species better adapted to evolving site conditions • Changes in forest succession
Effects of guides (i.e., uncertainty in target set to achieve guide objectives)	• Landscape-scale timing restrictions (e.g., marten cores, caribou mosaics) • Landscape pattern targets (e.g., Natural Disturbance Pattern Emulation Guidelines (NDPEG) disturbance template, NDPEG 80-20/90-10 standards) • No harvesting in Area of Concern (AOC) (e.g., stick nest buffers, fish habitat buffers) • Stand-level residual (e.g., residual patches) • Site-level residual (e.g., snags) • Operational restrictions (e.g., cultural heritage guide)

Appendix 3. Results of sub-theme rankings from survey responses

a. Forest resources inventory

Most survey respondents ranked 4 of the 6 sub-themes within forest resources inventory as creating a high source of uncertainty: stand age, species composition, site class, and stand height. Stand area estimation was the issue of least concern in this theme (Figure 1). In addition to sub-themes we provided, respondents identified a number of other areas of concern in this theme, including harvest rotation ages becoming younger, inaccuracy of age estimates, and the stocking and species composition of stands aged 10 to 40 years.

Barren and scattered (B&S) lands do not contribute to wood supply estimates, however when stocked stands are incorrectly assessed as B&S (or B&S lands misclassified as stocked stands), errors occur. This source of uncertainty was considered significant by 32% of respondents.

b. Growth and yield

The majority of respondents ranked most of the sub-themes in growth and yield as highly important. The most important sub-theme in this area was the timing and rate of stand break-up, identified by 73% of respondents (Figure 2).

c. Silviculture

Within the silviculture theme, 57% of respondents identified the difference between potential and actual yield curves of genetically improved stock as an important source of error in wood supply estimation, and 65% of them indicated there was high uncertainty around growth of stands regenerated using the CLAAG system. As shown in Figure 3, the variability of growth response to pre-commercial thinning and growth response to tending are considered only slightly less important.

d. Forest succession

Forest succession is the only case in which the overall theme and all associated sub-themes were ranked as important by more than 50% of respondents (Figure 4). The occurrence of successional transitions and the proportion of a stand succeeding were identified as important by more than two thirds of all respondents.

e. Other sub-themes

More than 30% of respondents considered sub-themes in natural disturbance, climate change, and the effects of forest management guides as high sources of error in wood supply estimation (Figures 5-9). Sixty four percent felt that the effects of disturbance by insects on forest succession and growth and yield created a high source of uncertainty.

Results for these sub-theme rankings are shown in following figures.

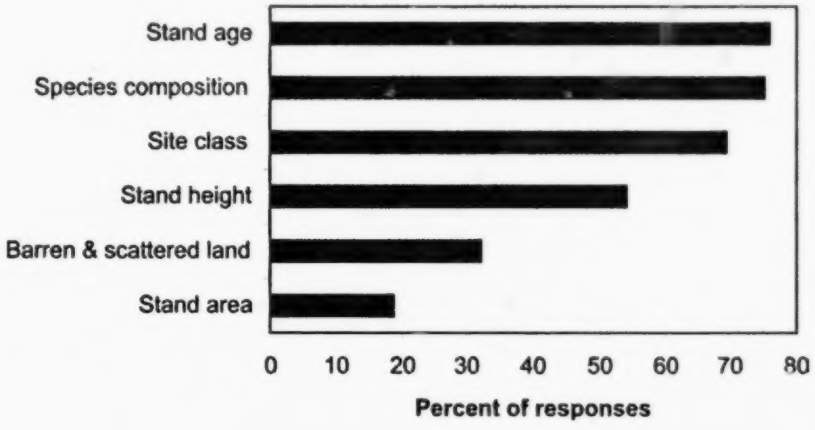

Figure 1. *Percentage of responses rating particular aspects of forest resources inventory as highly important sources of uncertainty in wood supply prediction.*

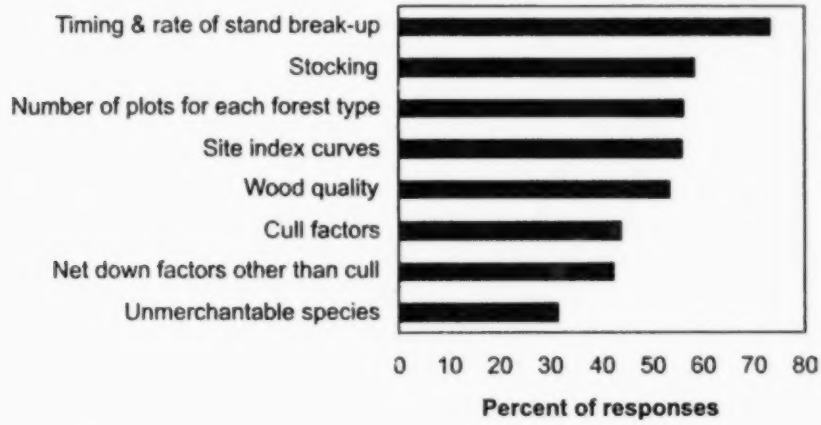
Timing & rate of stand break-up
Stocking
Number of plots for each forest type
Site index curves
Wood quality
Cull factors
Net down factors other than cull
Unmerchantable species
0 10 20 30 40 50 60 70 80
Percent of responses

Figure 2. *Percentage of responses rating particular aspects of growth and yield as highly important sources of uncertainty in wood supply prediction.*

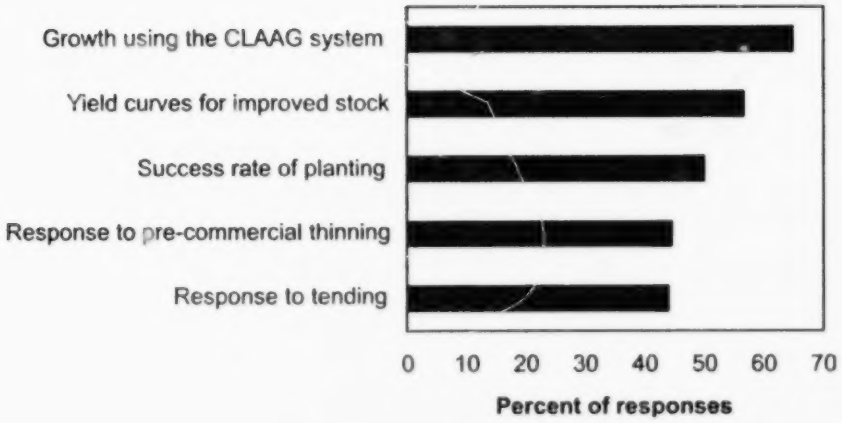
Growth using the CLAAG system
Yield curves for improved stock
Success rate of planting
Response to pre-commercial thinning
Response to tending
0 10 20 30 40 50 60 70
Percent of responses

Figure 3. *Percentage of responses rating particular aspects of silviculture as highly important sources of uncertainty in wood supply prediction.*

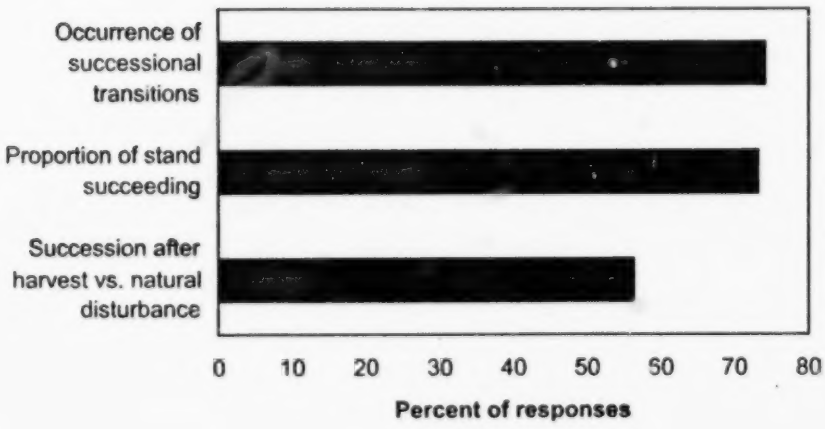
Occurrence of successional transitions
Proportion of stand succeeding
Succession after harvest vs. natural disturbance
0 10 20 30 40 50 60 70 80
Percent of responses

Figure 4. *Percentage of responses rating particular aspects of forest succession as highly important sources of uncertainty in wood supply prediction.*

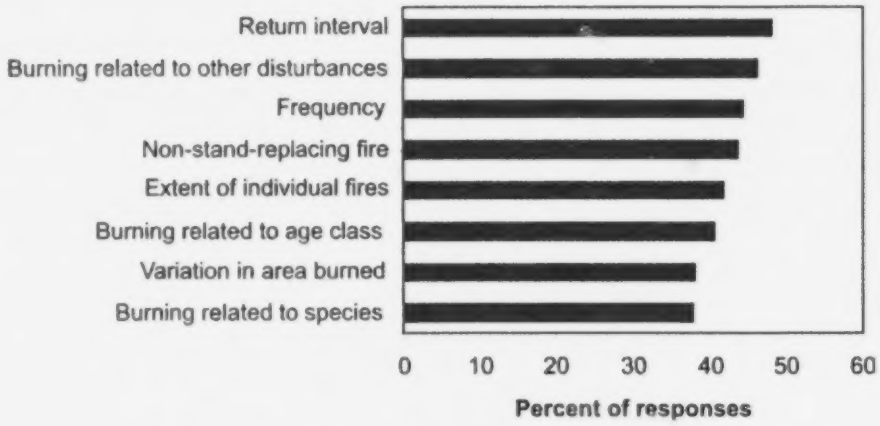

Figure 5. *Percentage of responses rating particular aspects of natural disturbance by wildfire as highly important sources of uncertainty in wood supply prediction.*

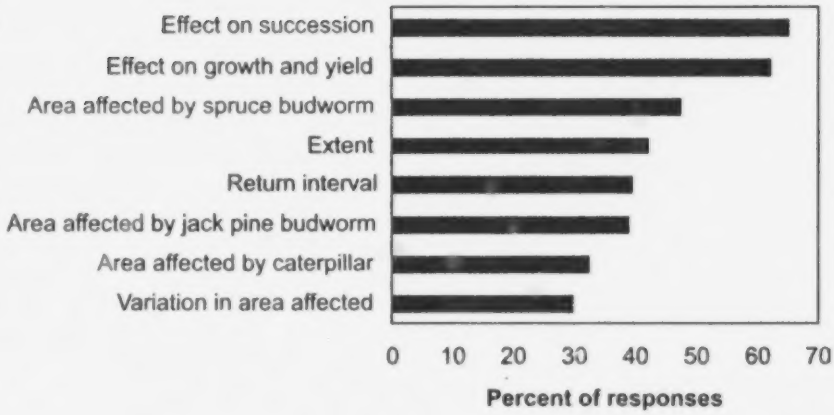

Figure 6. *Percentage of responses rating particular aspects of natural disturbance by insects as highly important sources of uncertainty in wood supply prediction.*

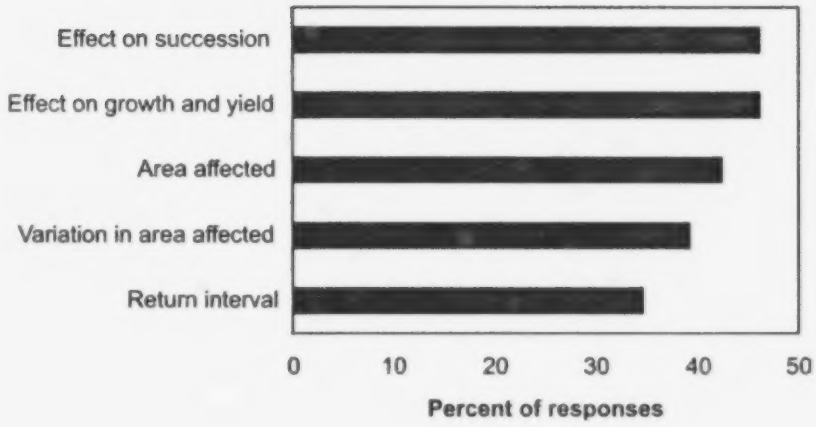

Figure 7. *Percentage of responses rating particular aspects of other natural disturbances as highly important sources of uncertainty in wood supply prediction.*

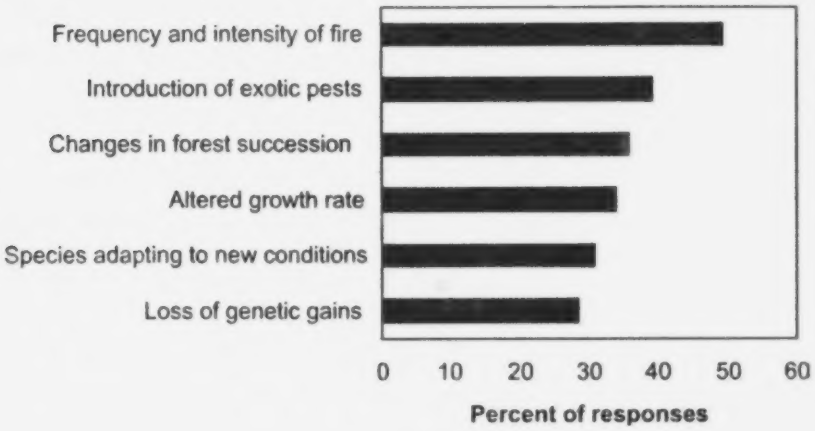

Figure 8. *Percentage of responses rating particular aspects of climate change and exotic species as highly important sources of uncertainty in wood supply prediction.*

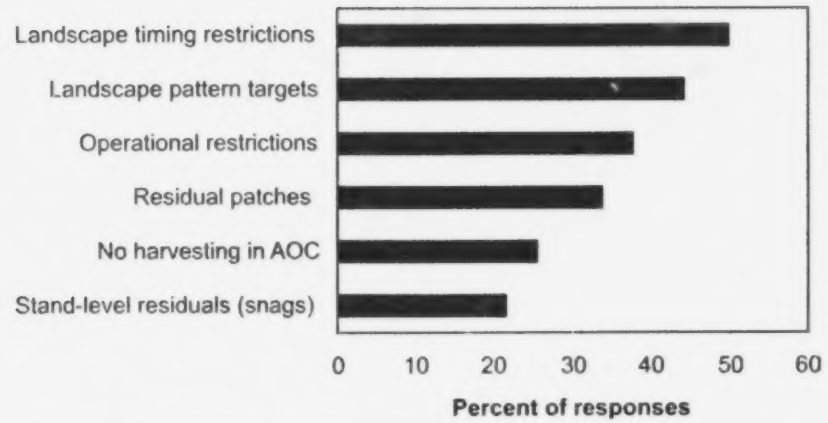

Figure 9. *Percentage of responses rating particular aspects of the effects of forest management guides as highly important sources of uncertainty in wood supply prediction.*

Appendix 4. Prioritized results of a workshop to identify research and science needs to address uncertainty in wood supply estimation

The top 28 priority areas for research and science related to wood supply as identified by workshop participants. The theme which each issue falls into is identified in parentheses.

1. (Forest resources inventory) Create a stronger linkage between forest resources inventory and growth and yield data.

2. (Forest succession) Produce more realistic succession information by developing approaches and obtaining data to predict and validate successional changes at various stages of stand development.

3. (Growth and yield) Create additional growth and yield curves for planted and naturally regenerated stands.

4. (Forest resources inventory) Update forest resources inventory more frequently.

5. (Growth and yield) Develop better data on factors affecting site productivity (e.g., soil moisture and nutrient regimes) and include these factors in growth and yield models.

6. (Other) Incorporate an economic analysis in forest management planning to differentiate wood supply based on cost (e.g., cost of wood to the mill).

7. (Forest resources inventory) Implement better statistical design for sampling and validating data in forest resources inventory.

8. (Effect of guides) Evaluate forest management guides to determine if they are meeting their objectives (through effectiveness monitoring), if they are being properly applied (compliance monitoring), and if they are having predicted effects (on non-target values) (effects monitoring).

9. (Climate change and exotics species) Identify the influence of climate on forest insect pest populations (both introduced and exotic pests).

10. (Other themes) Improve the prediction of silviculture effects on forest productivity.

11. (Forest resources inventory) Include better stand-level information in the forest resources inventory, for example:
    - Estimates of stand attributes (density, age, site class, height, species composition)
    - Information required to initiate the successional status of a stand
    - Information on uneven-aged stands.

12. (Growth and yield) Develop better data on early (0-20 yrs) stand growth.

13. (Natural disturbances) Produce and implement ecologically based estimates of fire cycles (currently, fire cycle is estimated independently for each Forest Management Unit leading to unrealistic differences between adjacent units).

14. (Forest resources inventory) Include information to allow development and implementation of wildlife habitat management at the stand level.

15. (Forest resources inventory) Develop standardized provincial approach to forest management units.

16. (Growth and yield) Develop growth and yield curves that reflect stand species composition. Current growth and yield curves have been developed for forest units, and therefore are unsuitable for individual stands (e.g., there is too much variability within forest units, tail-ends of growth and yield reflect successional changes at the forest unit, not at the stand level).

17. (Other) Improve accuracy of available harvest area prediction by taking into account reductions in this area due to economic and ecological constraints.

18. (Natural disturbances) Account for temporal and spatial variability of natural disturbances in modelling and planning.

19. (Other) Improve the Strategic Forest Management Model or consider alternative wood supply models to address current limitations in representing spatial issues and stochastic events.

20. (Forest resources inventory) Use finer imagery scale in photo interpretation (e.g., to capture information on understory vegetation).

21. (Guides) Improve (i.e., clarify and make more specific) guides' formulation and rules of their implementation.

22. (Forest succession) Develop integrated models of forest succession and growth and yield (currently, successional changes and growth and yield are modelled as two separate processes, leading to such effects as sudden jumps in yield when stand species composition changes).

23. (Natural disturbances) Develop better information on the effects of other natural disturbances (e.g., insects, diseases) on fire.

24. (Forest succession) Develop models predicting changes in variables accompanying succession such as down woody debris and understory vegetation.

25. (Growth and yield) Develop growth and yield models with changing utilization limits.

26. (Natural disturbances) Study long-term implications of fire suppression on fire cycle and available harvest area (AHA).

27. (Natural disturbances) Account for effects of natural disturbances other than fire (e.g., forest tent caterpillar, jack pine budworm, other insects, root diseases, blowdown).

28. (Other) Develop and implement in the wood planning process a system of standard forest units (SFU).

The following issues were identified by workshop participants but were unranked during the prioritization process. Issues are grouped by theme in no particular order.

Climate change

- Develop models that account for combined influence of soil, climate change, and human management practices on wood supply.
- Predict the influence of climate change and elevated CO_2 on forest growth / productivity.
- Include the influence of climate change on natural disturbance in wood supply models.
- Predict the influence of climate change on forest succession.

Forest resources inventory

- Include stand history attributes in forest resources inventory (e.g., past silvicultural treatments with dates of application).
- Develop educational materials and provide training on the use and limitations of forest resources inventory data (e.g., that current forest resources inventory was not designed to be used at the stand level).

Forest succession

- Develop succession models accounting for the effects of natural disturbances other than fire (e.g., insects, diseases).
- Develop and implement spatial prediction of forest succession at forest (landscape) level.

Growth and yield

- Develop density management diagrams for tolerant hardwoods.
- Produce better cull estimates for older stands.
- Collect more data and develop growth and yield curves for mixedwoods and some species: cedar (*Thuja occidentalis* L.), larch (*Larix laricina* (Du Roi) K. Koch), and white birch (*Betula papyrifera* Marsh.).
- Pursue assessment of alternative stand-level growth and yield models (e.g., Tree and Stand Simulator (TASS)).

Effects of guides

- Develop spatial models of wood supply prediction for proper implementation of guides.

Natural disturbances

- Develop and implement age class-dependent susceptibility of stands to natural disturbance.

Other

- Improve quantification of non-wood constraints in planning tools.

52039
(0.4k P.R. 06 11 30)
ISBN 1-4249-2590-8 (Print)
ISSN 0319-9118